United States Patent Application

of

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for

Method and Apparatus For Physiological Data Acquisition Via Sound Input Port Of Computing Device

Priority is claimed by provisional application No. 60/466,242 filed on 04/29/2003 entitled Method of data acquisition via microphone port of a computer.

Field of the invention

The invention relates to systems used for physiological data acquisition. It also relates to diagnostic systems.

Background of the invention

A sound input port is ubiquitously present in many types of devices including PCs, PDAs, cell phones, land line phones, voice recorders, etc., hereafter referred to as computing devices. This sound input port can be primarily of 3 types: 1) a microphone port, 2) a line port, and 3) a wireless port (e.g. Bluetooth Headset). These ports are similar in their frequency characteristics with two notable differences. A line port is designed for stronger "line-level" signals with peak-to-peak amplitude of approximately 10V. Furthermore a line port does not supply bias DC voltage. A microphone port is designed to receive smaller signals with peak-to-peak amplitude of approximately 100mV. In addition, a microphone port normally provides a bias DC voltage. Microphones lacking their own power supply rely on bias DC voltage for their power source. The invention disclosed herein can be used with either line, microphone, or wireless ports. Consequently, all sound input ports are hereafter referred to as "a microphone port" or "a sound port".

A microphone port allows analog data input into computing devices for further computation, visualization and data transmission. Unfortunately most computing devices

only allow one channel of data acquisition via a microphone port. Standard multiplexing methods for transmitting a plurality of data channels via a single channel do not work since the microphone port has a hardware lowpass filter. The invention disclosed herein does not use a multiplexing method. Rather, the invention uses amplitude modulation of a plurality of data channels to transmit the composite signal into a microphone port of a computing device. All signals can be demodulated in the computing device with no loss of data.

Devices for concurrent recording of two or more channels of physiological data are well known. US Pat. No 5,165,417, 5,844,997, 6,139,505, 6,394,967 to Raymond Murphy, the inventor herein, disclose multichannel sound recording system based on a multichannel A/D board.

US Pat. No. 4,053,951, to Hudspeth, et al. entitled Data acquisition, storage and display system discloses the device for medical data acquisition including temperature, respiration rate and pulse rate are measured and stored in an acquisition unit incorporating a circulating register for storing data covering many patients.

US Pat. No.5,701,904 to Simmons, et al., entitled Telemedicine instrumentation pack discloses a portable medical diagnostic apparatus which includes three types of data-gathering instruments: (1) visual instruments (eg, otoscope, ophthalmoscope, rhino-laryngoscope, macro lens and fundus camera); (2) an audio instrument (eg, electronic stethoscope); and (3) data-gathering instruments (eg, pulse oximeter and ECG monitor). The signals are transmitted to a remote site for analysis by medical personnel.

Although these devices fulfill the purpose of multichannel data acquisition they all rely on special data acquisition hardware which makes them expensive and cumbersome.

Recording two or more channels of data via the ubiquitous microphone port is advantageous for many reasons. The multichannel sound recording system disclosed herein is based on the existing microphone port and consequently does not require an addition of data acquisition hardware resulting in a cheaper and less cumbersome system.

Further, a highpass filter on the input of the microphone port prevents recording of data below 20Hz. Many physiological signals below 20Hz are of great importance, for example EKG and seismocardiogram. The invention disclosed herein uses amplitude modulation of a carrier frequency. The particular carrier frequencies are chosen from frequency range that is unaffected by the microphone port hardware filters. This allows recording of low frequency signals, that is signals below 20Hz, via the microphone port of the computing device.

Brief Summary of the Invention

The invention disclosed herein extends the recording frequency range of a microphone port to very low frequencies and allows a plurality of data channels to be transmitted into a computing device via the microphone port using multiple frequency bands. Briefly, amplitude modulation occurs in the hardware using a set of carrier frequencies. The resulting amplitude modulated signals are summed into a composite signal which is transmitted into the microphone port of the computing device. Demodulation occurs in the software. The composite signal can be transmitted to the computing device by wires, by wireless data communications, by a network of computing devices or by a combination of these means.

The stethoscopes are widely used by medical personnel to listen to body sounds. Unfortunately the stethoscopes do not allow recording or visualization of sounds, nor do they allow to easily relate heart sounds to the events of the heart cycle apparent on the EKG. In the preferred embodiment, referred thereafter as "EKG Stethoscope", the disclosed method is used to simultaneously transmit the audio signal from an electronic stethoscope and the corresponding electrical EKG signal into a computing device via the microphone port of the computing device. In other words, the EKG Stethoscope allows the medical practitioner to perform auscultation and obtain electrocardiogram at the same time. The recording/visualization device could be a personal computer, a PDA, a mobile phone, a land line phone or a voice recorder. The data can be transmitted via wire or wirelessly (for example using Bluetooth technology).

The EKG Stethoscope has the following advantages:

- A phonocardiogram can be visualized simultaneously with an electrocardiogram.
- Auscultation of heart sounds is greatly facilitated by knowing the event of the heart cycle visualized on the EKG.
- Automatic, that is computer based, heart sound analysis is facilitated by identification of events on the electrocardiogram.

The EKG Stethoscope system uses the fact that neither the EKG nor the audio signal requires the full bandwidth of the microphone port (which is 20Hz to 44,100Hz). Normally the EKG signal is between 0.5Hz and 300Hz, and body sounds are between 20Hz and 2000Hz. Therefore, there is sufficient bandwidth to transmit both EKG and sound into the microphone port of the computing device.

In an alternative embodiment physiological data from multiple sensors, such as acoustic pick-up sensors, are transmitted into the computing device via a single microphone port. Similarly, body sounds are limited in bandwidth to 2000Hz. Therefore, theoretically, up to 11 channels can be modulated and concurrently transmitted into a microphone port with bandwidth of 44,000Hz.

Brief Description of the Drawing

Fig. 1A is a flow chart of a system for implementing data acquisition from a plurality of data channels via a single microphone port of a computing device;

Fig. 1B is a flow chart of a system for implementing demodulation of a composite signal of Fig. 1A;

Fig. 2 is a block diagram of a system for implementing a preferred embodiment of the present invention;

Fig. 3 is a flow chart of the steps performed in Signal Conditioning and Modulation Circuit of Fig. 2.

Fig. 4 shows overall design of the EKG Stethoscope with EKG electrodes embedded into the chest piece as viewed from the bottom.

Fig. 5 is a data plot of the composite signal (top) separated by filtering into modulated EKG (middle) and audio signal (bottom).

Fig. 6 is a data plot of the amplitude modulated EKG (top), the EKG multiplied by carrier signal (middle) and the EKG lowpass filtered with a cutoff frequency equal to 25Hz resulting in a clean EKG signal (bottom).

Fig.7 is a data plot of the composite signal (top) and the recovered signals. The EKG signal is shown in the middle and heart sound is shown in the bottom.

Detailed Description of the Invention

Figure 1A is a flow chart of a system for implementing data acquisition from a plurality of data channels via a microphone port of a computing device. Input 1 **101** is first amplified by an Amplifier **102** and then is filtered by a Lowpass Filter **103** with cutoff frequency of f_{cutoff}. Further the resulting signal is multiplied by the carrier frequency $f_{carrier}$ **107** in an Analog Multiplier **104.** The resulting modulated input 1 signal is moved up on the frequency scale to occupy the interval from $f_{carrier} - f_{cutoff}$ to $f_{carrier} + f_{cutoff}$.

A plurality of inputs from Input 2 **108** to Input N **110** can be modulated by the corresponding carrier frequencies **109, 111.** All modulated signals are summed by a Summing Amplifier **105** to derive a composite signal output **106**. The composite signal can be then transmitted into the microphone port of the computing device via wire or wirelessly.

Consider an 8 channel data acquisition system transmitting data into a standard computer sound card with sampling rate of 44,100Hz. Each input channel of the 8 channel data acquisition system records data from a sensor with a bandwidth of 0Hz to 1,000Hz. All eight lowpass filters can be chosen to have cutoff frequency equal to 1,000Hz. Eight carrier frequencies can be chosen as follows: f1=2,500Hz, f2=5,000Hz, f3=7.500Hz, f4=10,000Hz, f5=12,500Hz, f6=15,000Hz, f7=17,500Hz, f8=20,000Hz. Amplitude modulation allows to distribute 8 data channels over the frequency range of the sound card. The carrier f1 modulated by input 1 occupies interval from 1,500Hz to 3,500Hz, the

carrier f2 modulated by input 2 occupies interval from 4,000Hz to 6,000Hz, ..., the carrier f8 modulated by input 8 occupies interval from 19,000Hz to 21,000Hz. The summing amplifier then sums eight amplitude modulated carrier frequencies into a composite signal. The composite signal is then transmitted into the microphone port of the computing device via wire or wirelessly.

Inside the computing device the composite signal is demodulated. As long as intervals occupied by modulated signals in the frequency domain are separated, it is possible to recover original signals with no loss. The demodulation flow chart is shown in Fig. 1B. The composite signal **121** is digitized by the computing device sound card. A digital bandpass filter 1 **122** is used to separate the frequency band around the carrier frequency 1 **123** from $f_{carrier} - f_{cutoff}$ to $f_{carrier} + f_{cutoff}$. The resulting signal is multiplied by a digitally generated carrier frequency 1 **123** in a digital multiplier **128**. The resulting signal is filtered by a Digital Lowpass Filter **129**. As long as the carrier frequency **123** is equal to the carrier frequency **107** of Fig. 1A, the resulting Output signal 1 **130** is equal to the Input 1 **101** of Fig. 1A.

Similarly, the composite signal **121** can be broken down into a plurality of frequency bands by digital bandpass filters 2 **124** through N **126.** Each band is multiplied by the corresponding carrier frequency **125** through **127** and consequently filtered with lowpass filters. The resulting demodulated output signals 2 **131** through N **132** are indistinguishable from the corresponding inputs **108** through **110**. These outputs can now be recorded, visualized, and analyzed by the computing device.

In the example of the eight channel data acquisition system mentioned above the digital bandpass filter 1 can be a Hamming bandpass filter with 512 taps and pass band

from 1,500Hz to 3,500Hz; the digital bandpass filter 2 can be a Hamming bandpass filter with 512 taps and pass band from 4,000Hz to 6,000Hz;....; the digital bandpass filter 8 can be a Hamming Window bandpass filter with 512 taps and pass band from 19,000Hz to 21,000Hz. Further each channel is digitally multiplied by the corresponding carrier frequency. The output of the digital bandpass filter 1 is multiplied by the carrier frequency 1 equal to 2,500Hz; the output of the digital bandpass filter 2 is multiplied by the carrier frequency 2 equal to 5,000Hz, ...; the output of the digital bandpass filter 8 is multiplied by the carrier frequency 8 equal to 20,000Hz. Further the result of multiplication is filtered by a digital lowpass filter. All digital lowpass filters can be Hamming Window lowpass filters with 512 taps and pass band between 0Hz and 1000Hz.

Figure 2 shows a block diagram of a system for implementing a preferred embodiment of the present invention, the EKG Stethoscope. The chest piece **201** picks up an acoustic signal from the body, converts the acoustic energy into an electrical signal and than transmits the signal via wire or wirelessly **204** into a Signal Conditioning and Modulation Box **206**. Further the electrocardiographic signal from the patient's skin is picked up by EKG electrodes **203** and transmitted via wire or wirelessly **205** into a Signal Conditioning and Modulation Box **206.** The composite signal from the Signal Conditioning and Modulation Box **206** is transmitted to the Microphone Port of the computing device **207**.

Figure 3 describes the flow chart of the steps performed in the Signal Conditioning and Modulation Box **206** of Fig. 2. The EKG input **301** from EKG electrodes placed on patient's skin is amplified by a standard EKG amplifier **302** with a gain of 1V/mV. Further it is filtered by a bandpass filter 0.5 to 120Hz and 60Hz notch filter (-23dB). The resulting

amplified and filtered EKG is multiplied by the carrier signal **307** with frequency 3,000Hz in the Analog Multiplier **304**. Note that the resulting modulated EKG signal is located in the frequency band centered around the carrier frequency, that is between 2,700Hz and 3,300Hz.

The audio input **308** from sound pickup placed on the patient's skin is amplified by the Audio Amplifier **309** and filtered by a Lowpass Filter **310** with a cutoff frequency of 2,000Hz. The modulated EKG signal is then summed with the amplified and filtered audio signal by the Summing amplifier **305**. The resulting composite signal output **306** is transmitted via wire or wirelessly into the computing device.

Fig. 4 shows the overall design of the EKG Stethoscope with three EKG electrodes **403** mounted on the chest piece **401** around the diaphragm **402**. The physician can move chest piece around the chest to collect data at different sites. The suitable EKG electrodes can be made of electroconductive material and have an area of $1cm^2$. The sound amplification can be either electronic via wire or acoustic via tubing **404**. The suitable microphone for the electronic sound amplification can be omnidirectional electret microphone embedded into the chest piece. The EKG Stethoscope allows a medical practitioner to avoid application of separate EKG electrodes. The result is a faster and less cumbersome procedure.

The computing device of the EKG Stethoscope can be a PDA such as Compaq iPAQ5450 Pocket PC. The composite signal **306** of Fig. 3 is transmitted to the PDA's microphone input port. The transmission can be via the wire connected to an external 3.5mm microphone jack or wirelessly via bluetooth headset protocol. No modification or special hardware is required with iPAQ5450. The PDA can be programmed to conduct the

demodulation of the composite signal. The PDA can display the results of demodulation on its screen and store the data for later retrieval/transfer. Also, the PDA can be programmed to perform the automatic analysis of the EKG and acoustic signals.

Inside the computing device the composite signal **306** of Fig. 3 is demodulated into an EKG and audio signals for further recording, visualization, and analysis. Fig. 5 is a data plot of a composite signal **501** recorded from a subject. The composite signal **501** is first filtered by a lowpass filter with cutoff frequency of 2000Hz. The resulting signal is a pure audio signal **503**, Fig.5. Further, the composite signal **501** is filtered by a bandpass filter with cutoff frequencies of 2700Hz and 3300Hz. The resulting signal is the modulated EKG signal **502.**

Figure 6 shows the process of demodulation of the EKG signal **502** of Fig. 5. The modulated EKG signal **601** is multiplied by the carrier frequency. The result of digital multiplication is the signal marked **602**. Further, the signal **602** is filtered by a lowpass filter with a cutoff frequency of 25Hz. The resulting signal is a clean EKG signal **603**.

Fig.7 is a data plot of the composite signal **701**, same as **501** of Fig. 5, and the demodulated EKG **702,** same as **603** of Fig. 6, and sound signal **703**, same as **503** of Fig. 5, shown in the stack mode.